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Summary

A generating system of a synchronous strobed laser light sheet has been designed and used for flow visualization of a helicopter rotor model. The strobe circuit of the laser light sheet was designed to allow selectable blade-position viewing, strobe duration, and multiple pulses per revolution for rotors having two to nine blades. A slip-sync mode permits slow-motion visualization of the flow field over complete rotations of the rotor.

The system has been tested in the NASA Langley 14- by 22-Foot Subsonic Tunnel to make two-dimensional flow field cuts of a four-bladed rotor operating at wind-tunnel speeds up to 79.25 m/sec (260 ft/sec). Between runs, a calibration grid board was placed in the plane of the laser sheet and recorded with the video camera at the position used to record the flow field.

Introduction

Light sheets generated with either coherent or noncoherent sources have found widespread applications to flow visualization (refs. 1–5). A survey of techniques used to generate light sheets included cylindrical rods and lenses, rotating glass blocks, anamorphic prisms, Bragg cells, and mirrored galvanometers (refs. 6–8).

The purpose of this paper is to describe the generating system of the synchronous strobed laser light sheet that was developed for the NASA Langley 14- by 22-Foot Subsonic Tunnel. Also presented in this paper are some typical results that were obtained by using this system during actual tunnel testing.

A laser light sheet generating system using a cylindrical rod and a lens was developed for use in the 14- by 22-Foot Tunnel. The system incorporated a strobed laser light sheet that was synchronized to the blade motion of a helicopter rotor model that was being tested in the low-speed tunnel. Using this system, the illumination of smoke (vaporized propylene glycol) entrained in the flow passing around the blades of the model can reveal vortices produced by the blades. The design of the system included the capability to have an adjustable triggered delay of the strobe, an adjustable strobe pulse width, a selectable number of blades to view, and a slip-sync mode for real-time slow-motion flow visualization. Post-run quantitative data on such features as the size, position, and trajectory of the blade-tip vortices were extracted from the video images by recording a calibration grid placed in the plane of the light sheet between each tunnel run with the video camera in the same position that was used to record the flow field.

This work was a combined effort by the NASA Langley Research Center, Bell Helicopter Textron, and the Aerostructures Directorate of the U.S. Army Aviation and Technology Activity—Aviation Systems Command (USAARTA-AVSCOM).

Generation of the Light Sheet and Flow Visualization

A compound cylindrical-lens assembly was used to spread out the laser beam in order to generate a single sheet of laser light. Figure 1 illustrates the system as it was installed in the test section of the wind tunnel. An existing argon-ion laser that is used in a dedicated laser velocimeter (LV) scanning system was used as the light source for the generation of the light sheet. The LV system was used to interrogate the flow so that more-detailed velocity measurements could be made of the visualized flow phenomenon. The laser was operated in the "all lines mode" with an output of approximately 5 W. The laser beam was directed to the optics package that was magnetically secured to the floor of the test section. (See fig. 2.) The beam first struck a folding mirror that directed the beam onto a 6.35-mm- (0.250-in-) diameter glass rod diverging the beam in one axis only. This produced a triangular sheet of light with a divergence angle of 15°. Once the initial system setup was completed at the facility, a cylindrical lens was added after the glass rod in order to reduce the divergence angle to 10° to increase the intensity of the light sheet (ref. 9).

To visualize the flow, the area of interest in the flow volume was seeded with vaporized propylene glycol smoke injected upstream of the model (ref. 10). The propylene glycol particles scattered the laser light striking it. The pattern of light scattered by the propylene glycol was brightest in the transmitted or forward-scattered direction. For this reason, the video camera was located upstream of the model to view the light sheet from the forward-scattered direction. All flow visualization video records were obtained from the silicon-intensified target (SIT) camera because of the low integrated intensity of the short-duration pulsed light sheet. The SIT camera can produce a usable picture with a scene brightness of 2.5×10^{-4} ft lambert. The camera output was recorded with a standard VHS recorder.

Synchronizing the Light Sheet

The following describes the method of controlling the illumination relative to the rotor position.

Shaft encoders, attached directly to the rotor drive shaft, supply two separate signals: a single pulse per revolution (1 PPR) and 1024 pulses per revolution (1024 PPR). The two signals, having equal pulse widths, are phase synchronous and transistor-transistor logic (TTL) compatible. The single pulse per revolution (1 PPR) occurs when blade number "1" is parallel to the longitudinal axis of the helicopter to the rear of the rotor hub. The 1024-PPR signal is a square wave. The single and 1024-PPR signals are inputs to the synchronizing circuit. Figure 3 is a block diagram of the synchronizing circuit (with the exception of the slip-sync generator that was added after the initial tunnel tests were completed). The output of the synchronizing circuit drives a Bragg cell that strobes the light sheet. The first step in generating this output pulse begins in the delay generator that utilizes both shaft-encoder signals. (See fig. 4.) A four-digit programmable counter is loaded with the user-selectable delay upon being triggered by the single PPR signal after passing through a monostable multivibrator. Subsequent pulses from the 1024-PPR signal decrease the count until zero is reached. The zero carryout pulse (CO) occurs when the count reaches zero. This pulse occurs once per revolution and is delayed from the single PPR signal by the user-set delay. The output pulse is routed to the "number of blades" circuit, the first part of which is a phase lock loop (PLL) circuit as shown in figure 5.

The pulse from the delay generator becomes the input to a 4046 complementary metal oxide semiconductor (CMOS) PLL integrated circuit. The 4046 contains a voltage-controlled oscillator (VCO) and a phase detector. The output from the VCO is divided by the 4029 programmable divider. The divisor is selected by the user with a single-digit thumbwheel switch. Divisions from 1 to 9, corresponding to one to nine blades, are selectable. Selection of blade number "1" allows the flow field to be examined for a single blade in the rotor disk. For rotors with multiple blades, selection of other digits can increase the number of strobes per revolution and, hence, the brightness of the video image. For example, with six blades, selection of 6, 3, 2, or 1 will produce a meaningful display. For a nine-bladed rotor, selection of 9, 3, or 1 would be usable.

The output from the 4029 is compared with the input pulse rate by the phase detector in the 4046. The phase-detector output is low-pass filtered by R_A, R_B, and CF. The filtered output is used to control the 4046 VCO. Once locked, the output from the VCO is *"N"* times the input pulse rate, where N denotes the selected number of blades and is phase synchronous with the input signal. Dual monostable multivibrators (4098) are used to shape the output signal from the programmable divider and the VCO. The pulse from the number of blades circuit is then routed to the "strobe length" circuit.

The strobe length circuit shown in figure 6 is used to determine the output pulse length and, hence, the duration of the light sheet flash. The strobe length circuit is triggered by the output from the "number of blades" circuit which sets the 4013 set-reset multivibrator. Once set, the 4013 output goes high and is the output strobe. It also is used to gate 1024 pulses per revolution to the 4029 programmable counter. The 4029 counter is preset by the operator to the desired pulse length selected on a single-digit thumbwheel switch. The 4029 counts down to zero. At zero, a carryout pulse resets the 4013, thus terminating the output, and reloads the 4029 counter. The 4013 output is buffered by a set of inverters located on the "number of blades" circuit card (see fig. 5) and controls the external Bragg cell driver.

The circuit shown in figure 7 was developed to incorporate slip-sync or slow-motion capability. The circuit utilizes a 4059 programmable divider. In normal or "sync" operation, the encoder outputs from the model are fed straight to the previously described circuits. For "slow" or "fast" operations, the encoder output of 1024 pulses per revolution is still used directly. But the encoder single PPR signal is replaced by a synthetic single PPR signal. In the fast operation, the 4059 integrated circuit is programmed to divide the 1024-PPR signal by 1023 to produce an output that is slightly faster than the true 1-PPR signal. Similarly, in the slow operation, the 4059 is programmed to divide by 1025.

Strobing the Light Sheet

The light sheet was strobed by the addition of an acoustic-optical Bragg cell shutter (placed between the laser and the optics package) that transmits a zero order and produces first-order light beams. The zero-order beam was unused and blocked, and the first-order beam from the Bragg cell was chopped by the signal being fed to the Bragg cell from the synchronization circuit. The Bragg cell introduces color dispersion. This chromatic dispersion was corrected by inserting a dual prism assembly into the optical path just after the beam exits the Bragg cell. The dual prism assembly consists of two rotatable prism wedges that were adjusted to converge the different wavelengths back onto a common optical axis.

Video Acquisition and Calibration

Standard VHS video recordings were made of the four-bladed-rotor flow fields at tunnel speeds up to 79.25 m/sec (260 ft/sec). These recordings were made with the SIT camera located forward of the model. The optics package was positioned on the floor of the test section at one of four possible positions in order to visualize the flow patterns at 20, 60, –20, and –60 percent of the blade length as illustrated in figure 8. The camera was placed on the starboard side of the model when the 20- and 60-percent positions were recorded and on the port side of the model to obtain video recordings from the –20- and –60-percent positions. After video records were made with the optics package at a particular position, the wind tunnel was stopped and the laser was turned off. A calibration grid was then placed in the test section in the plane of the light sheet. The grid was then recorded with the video camera. Post-run analysis using the video grid records as an overlay for individual frames on the flow field video allowed the determination of size, direction, and spacing of the vortex patterns.

Results

The laser light sheet system described in this paper was developed for the visualization of the flow around rotor models. A photograph of the model installed in the test section of the 14- by 22-Foot Tunnel is shown in figure 9. The wind-tunnel tests were performed to compare actual vortex locations with predicted locations in order to understand the wake structure. Each blade tip produces a vortex. Establishing successive vortex locations permits the researcher to determine the trajectory of the wake generated by the rotor. Figure 10 depicts the field of view of the SIT camera on the port side of the model with the test section lights on, the tunnel running, and the smoke and light sheet operating. The rotor model was tilted 5.8° forward into the flow. In this particular video frame the light sheet was set at the –60-percent position. Figure 11 shows an example of how well the light sheet reveals consecutive blade-tip vortices. This photograph was taken under the same conditions as figure 10 except with the test section lights turned off. The top of the second vortex from the left appears to be clipped. This clipping is produced by the blade protruding through the plane of the light sheet. Figure 12 is a composite photograph constructed by superimposing the calibration grid board video record and a video frame similar to that in figure 11.

Another type of composite photograph that can be made is done by superimposing two video frames of similar data runs with all the tunnel conditions the same except with the smoke plume in different locations. Figure 13 illustrates the flow conditions of both the upper and lower portions of the rotor disk by using this technique.

All the flow field photographs shown to this point were taken with the camera set to view the flow patterns of the –60-percent position. In these photographs the airflow was moving left to right and the rotor blade tips were moving in the same direction as the airflow. Figure 14 shows the flow pattern at the 60-percent position in which the airflow was moving right to left and the blade rotation was in the opposite direction from the airflow. The dark streak through the photograph is produced by the blade obscuring the light sheet in that area.

Concluding Remarks

The laser light sheet system at the NASA Langley 14- by 22-Foot Subsonic Tunnel was an evolving system during tunnel testing of the helicopter model. Initially, the light sheet was configured to generate a light sheet with a dispersion angle of approximately 15°. Upon installation in the tunnel, the light sheet was reconfigured with a dispersion angle of about 10° to increase the light flux density of the sheet and increase the contrast of the video image. When it was discovered that the optical Bragg cell was introducing a color dispersion, a dual prism assembly was added to minimize the separation. Finally, the capability to make slip-sync video recordings was required and added to the system.

The system is capable of "freezing" the flow field at any one of 1024 possible angular blade positions and of recording these images on standard VHS video tape. The system circuitry can easily be set based on the number of blades that the model has. The system has an adjustable pulse length for exposure control and can be used in the synchronized or slip-sync mode. By recording the grid board with the video camera in the same position that was used to record the flow field, the size, location, and trajectory of the vortices can be extracted from the flow field video recordings during post-run processing.

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March 27, 1991

References

1. Snow, Walter L.; and Morris, Odell A.: *Investigation of Light Source and Scattering Medium Related to Vapor-Screen Flow Visualization in a Supersonic Wind Tunnel.* NASA TM-86290, 1984.

2. Richwine, David M.; Curry, Robert E.; and Tracy, Gene V.: *A Smoke Generator System for Aerodynamic Flight Research.* NASA TM-4137, 1989.

3. Leighty, B. D.; Franke, J. M.; Jones, S. B.; and Rhodes, D. B.: A Two-Mirrored Galvanometer Laser Light Sheet Generator. AIAA-88-4680, Sept. 1988.

4. Kjelgaard, Scott O.; Sellers, William L., III; and Weston, Robert P.: Flowfield Survey Over a 75° Swept Delta Wing at an Angle of Attack of 20.5°. AIAA-86-1775, June 1986.

5. Booth, E. R., Jr.: Experimental Observations of Two Dimensional Blade-Vortex Interaction. AIAA-87-2745, Oct. 1987.

6. Beiser, Leo; and Marshall, Gerald F., eds.: *Laser Scanning Components and Techniques–Design Considerations/Trends, Volume 84 of Proceedings of the Society of Photo-Optical Instrumentation Engineers,* 1977.

7. Merzkirch, Wolfgang: *Flow Visualization.* Academic Press, Inc., 1974.

8. Trebino, Rick: Achromatic N-Prism Beam Expanders; Optimal Configurations. *Appl. Opt.,* vol. 24, no. 8, Apr. 15, 1985, pp. 1130–1138.

9. Leighty, Bradley D.; Rhodes, David B.; Jones, Stephen B.; and Franke, John M.: A Synchronous Strobed Laser Light Sheet for Helicopter Model Rotor Flow Visualization. *Proceedings of the 36th International Instrumentation Symposium,* Instrument Soc. of America, 1990, pp. 9–22.

10. Bruce, Robert A.; Hess, Robert W.; and Rivera, José A., Jr.: *A Vapor Generator for Transonic Flow Visualization.* NASA TM-101670, 1989.

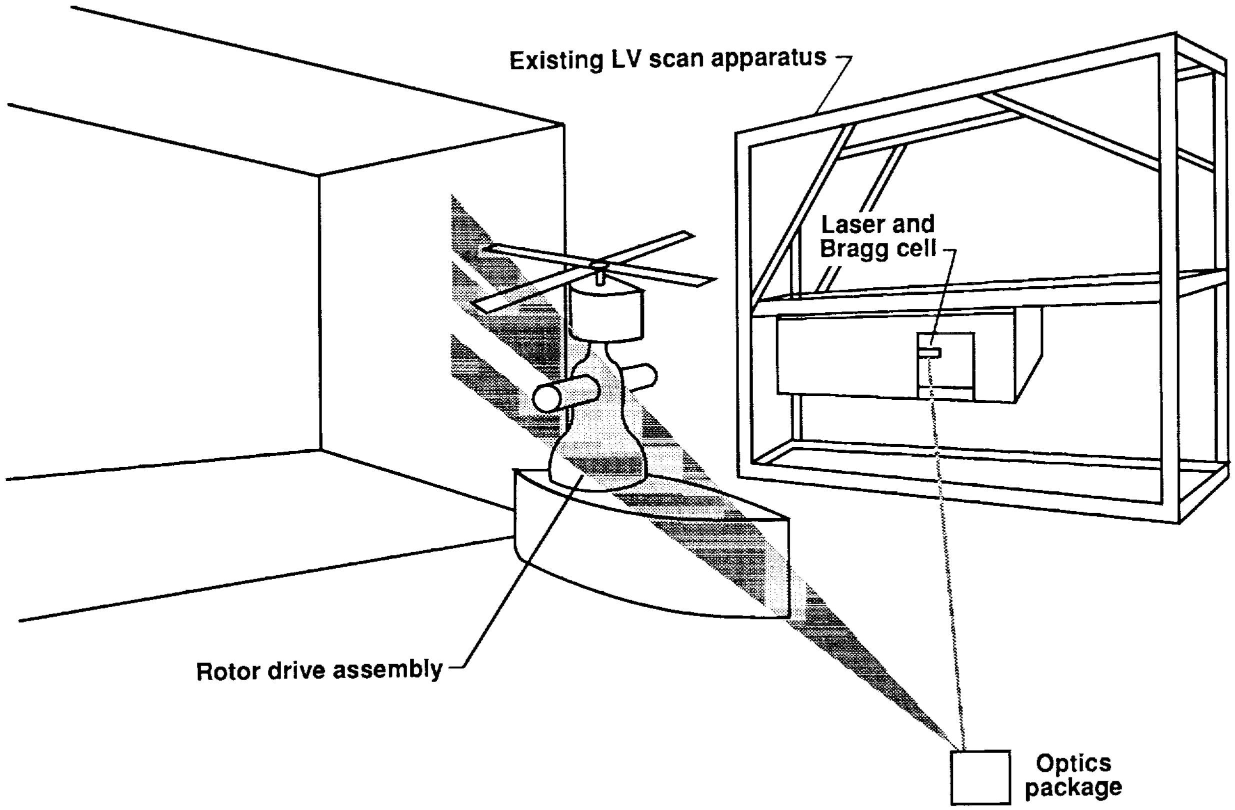

Figure 1. System installed in test section of the 14- by 22-Foot Tunnel.

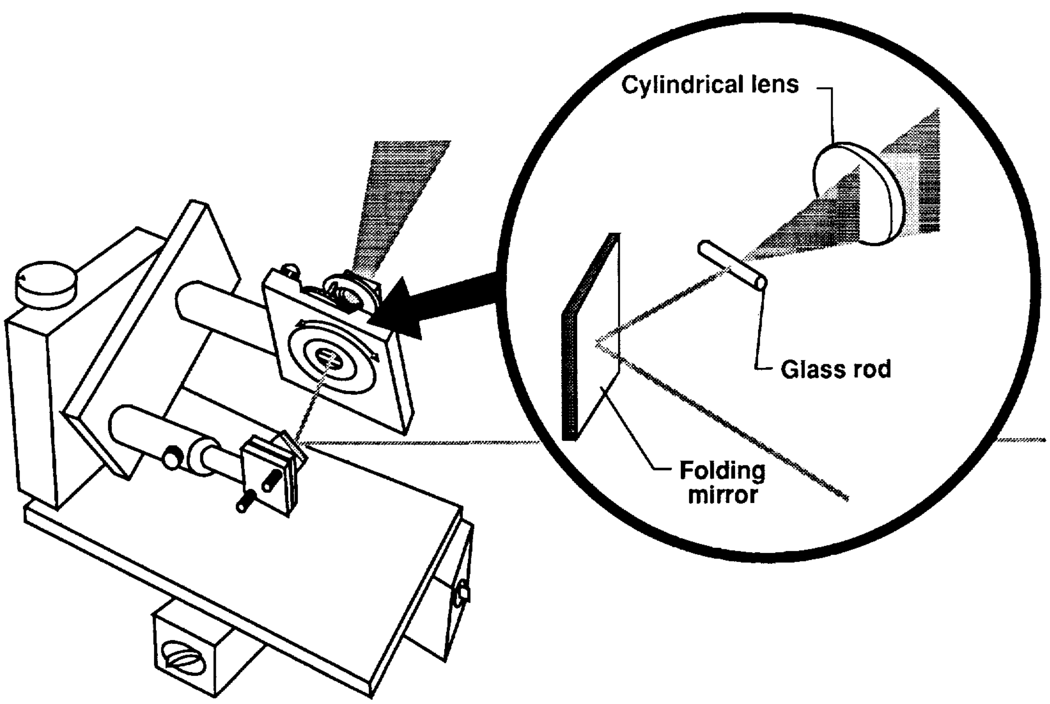

Figure 2. Sketch of optics package generating the light sheet.

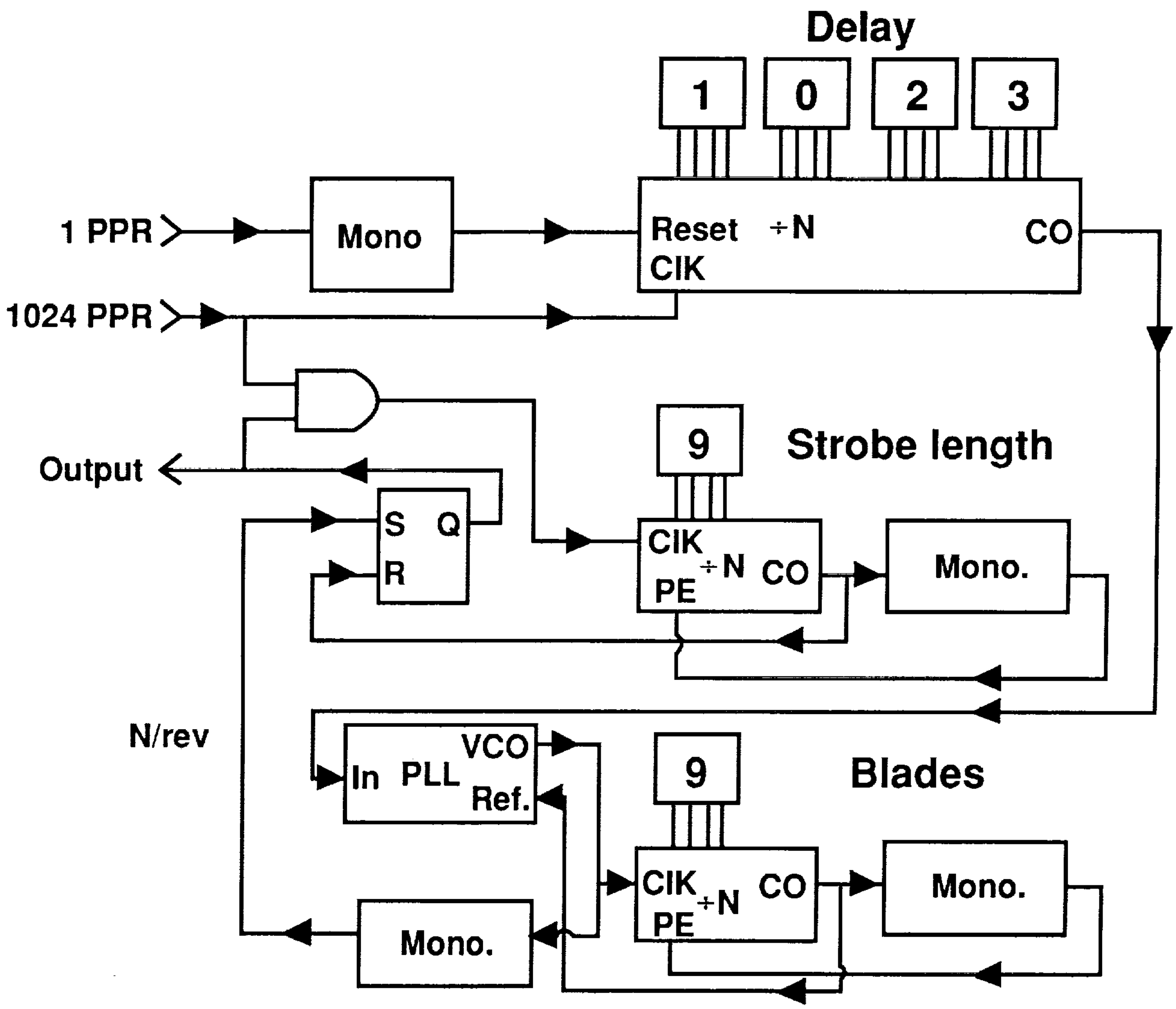

Figure 3. Block diagram of synchronizing circuit.

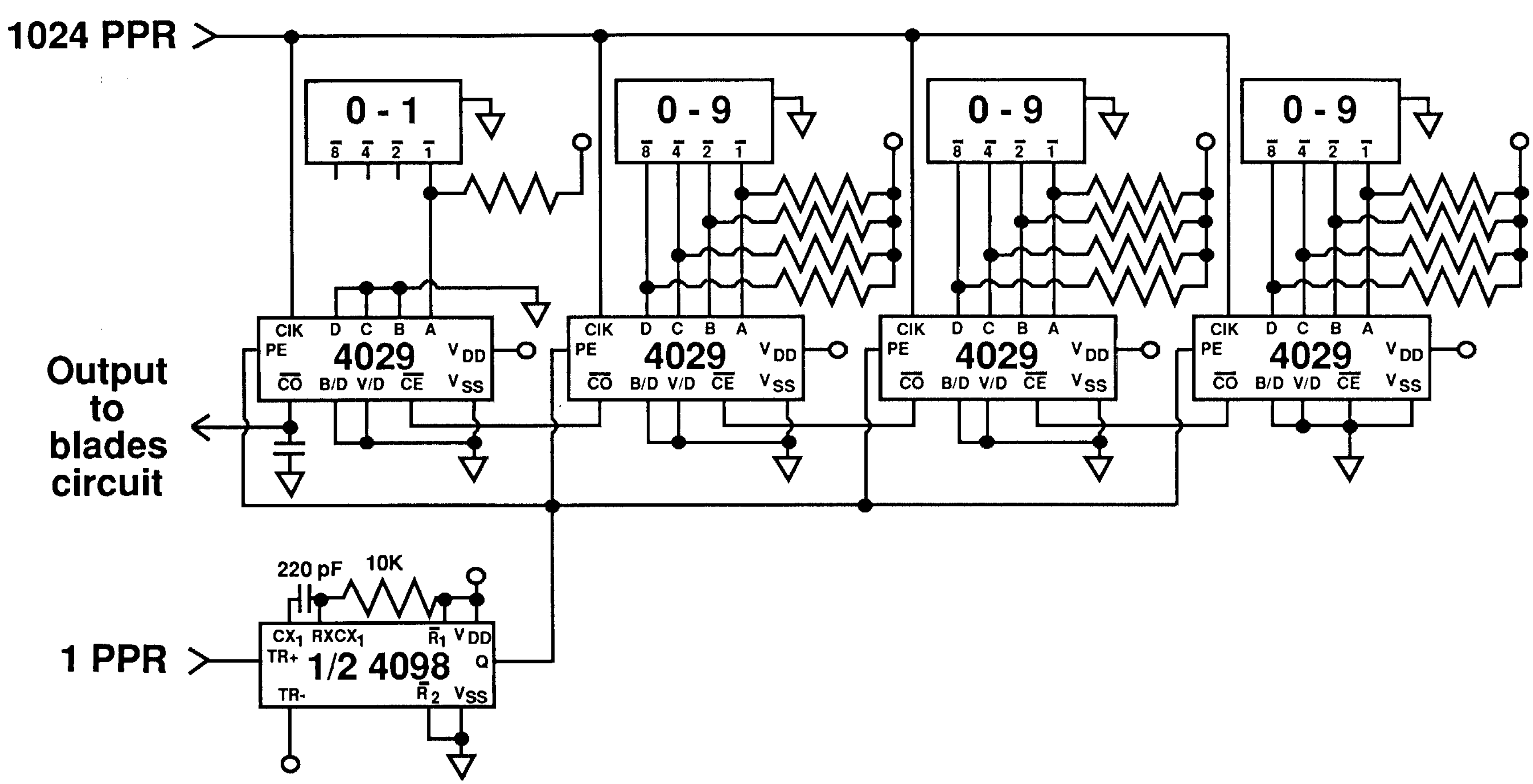

Figure 4. Schematic diagram of delay circuit.

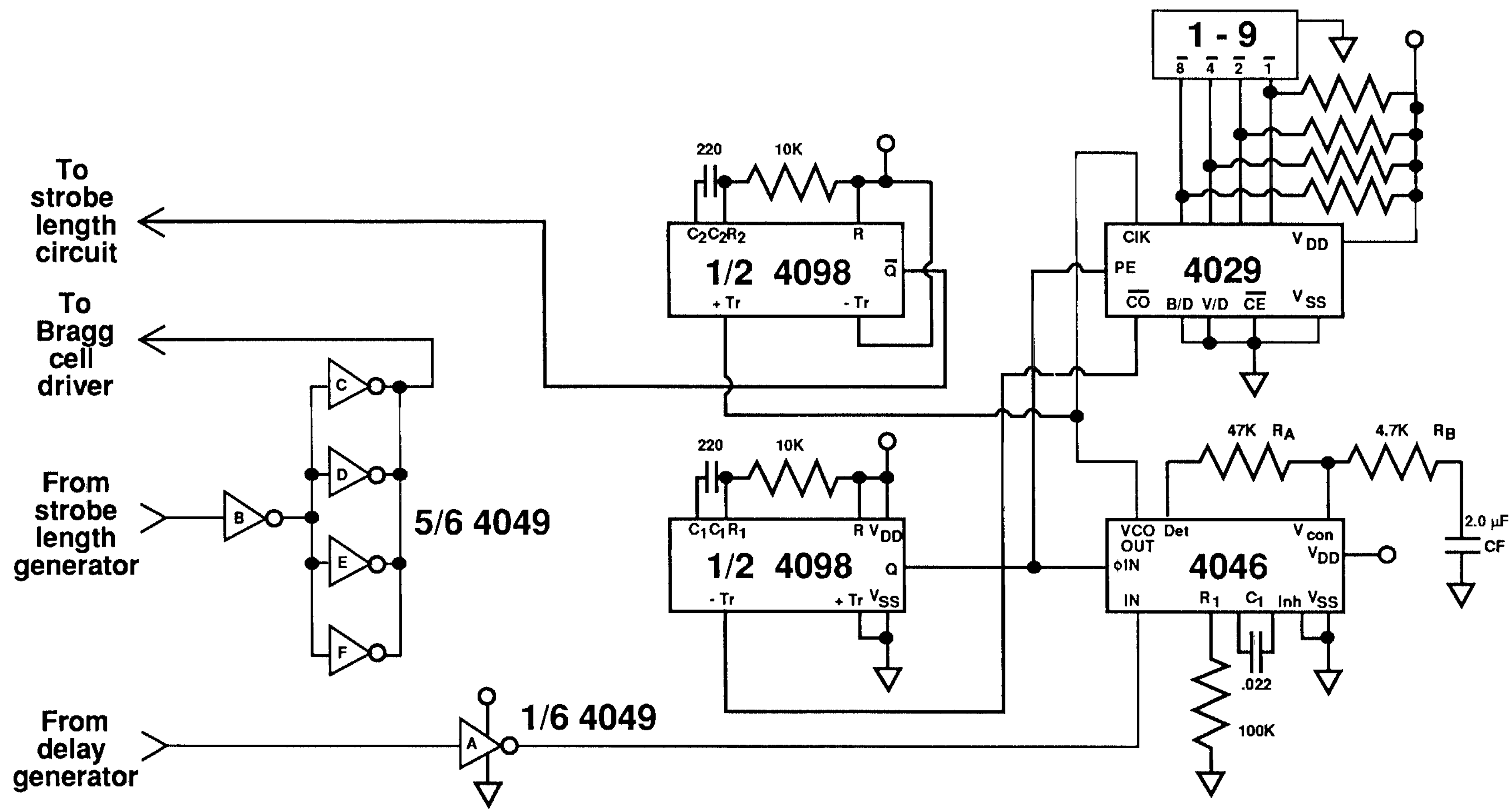

Figure 5. Schematic diagram of phase lock loop.

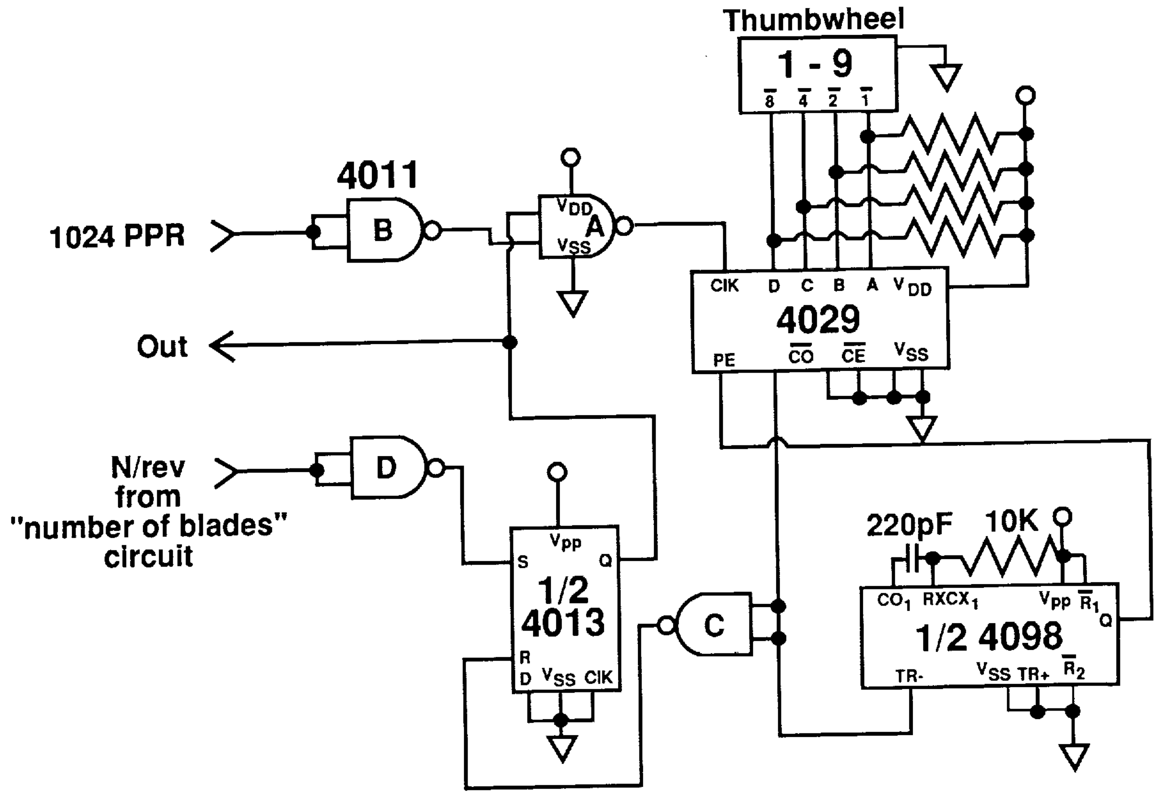

Figure 6. Schematic diagram of strobe length circuit.

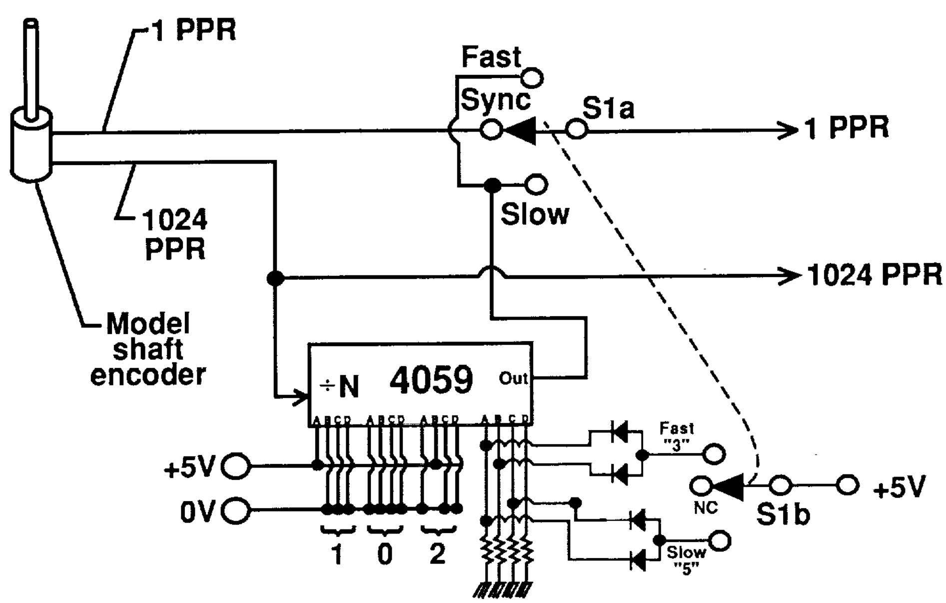

Figure 7. Schematic diagram of slip-sync circuit.

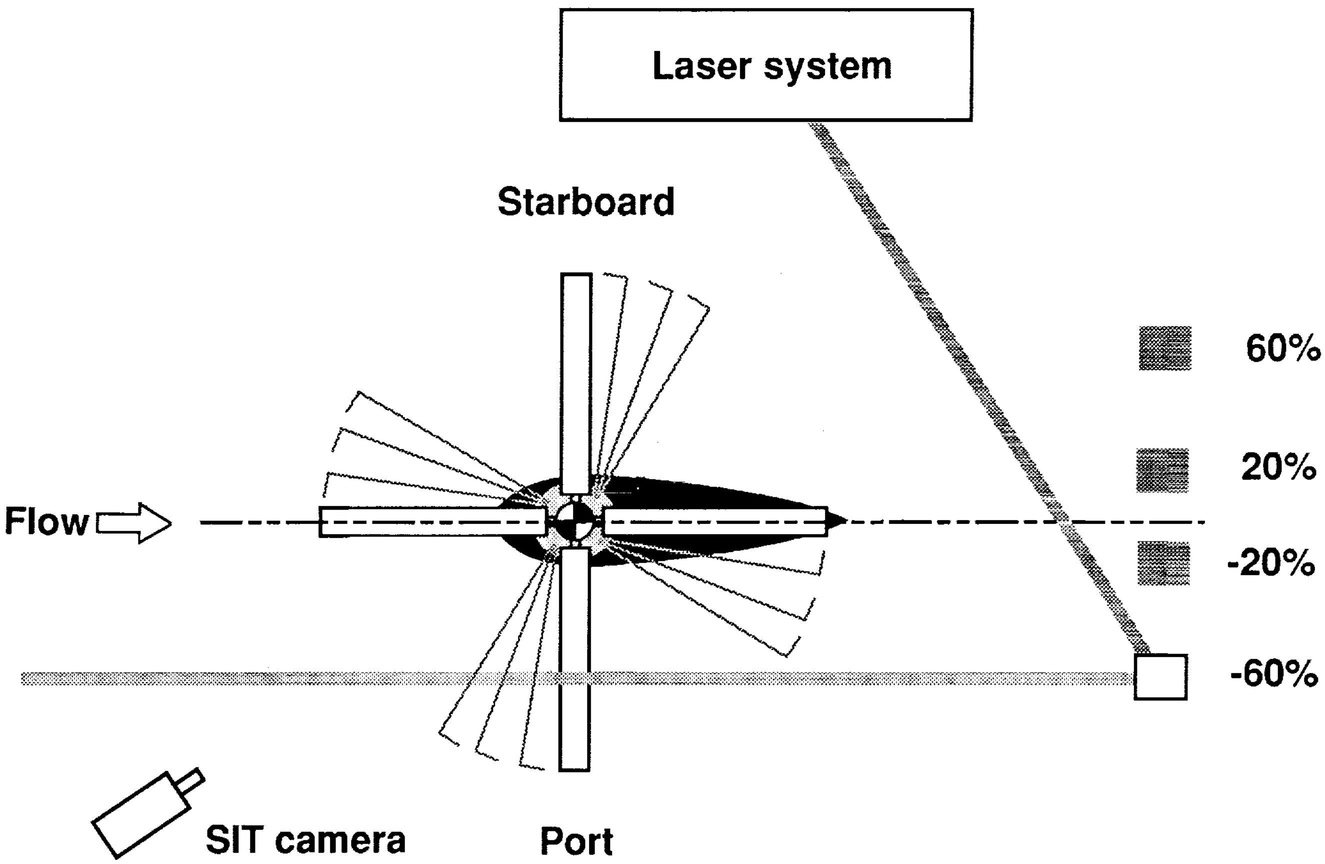

Figure 8. Locations of camera and optics package.

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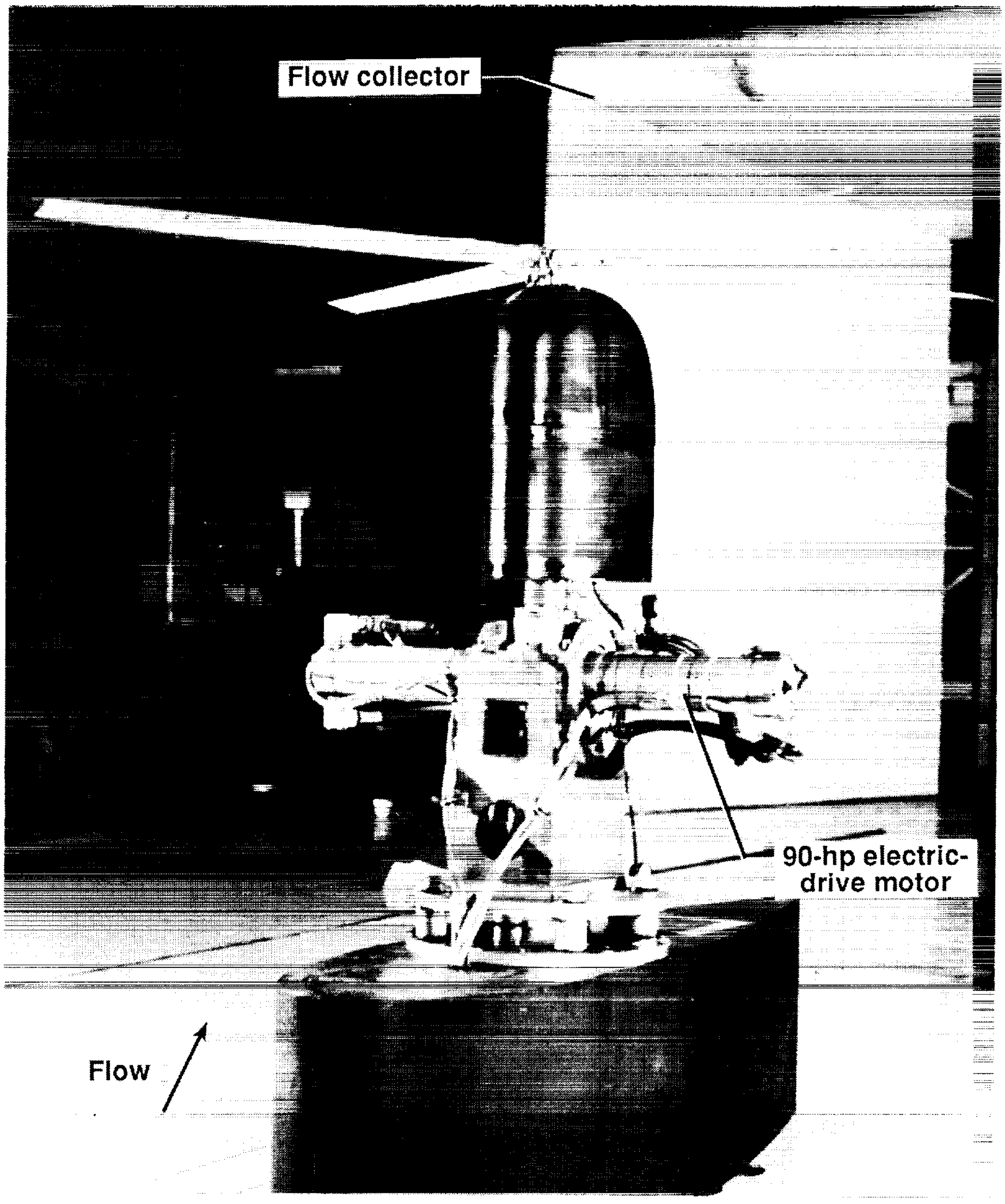

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Figure 9. Model installed in test section of the 14- by 22-Foot Tunnel.

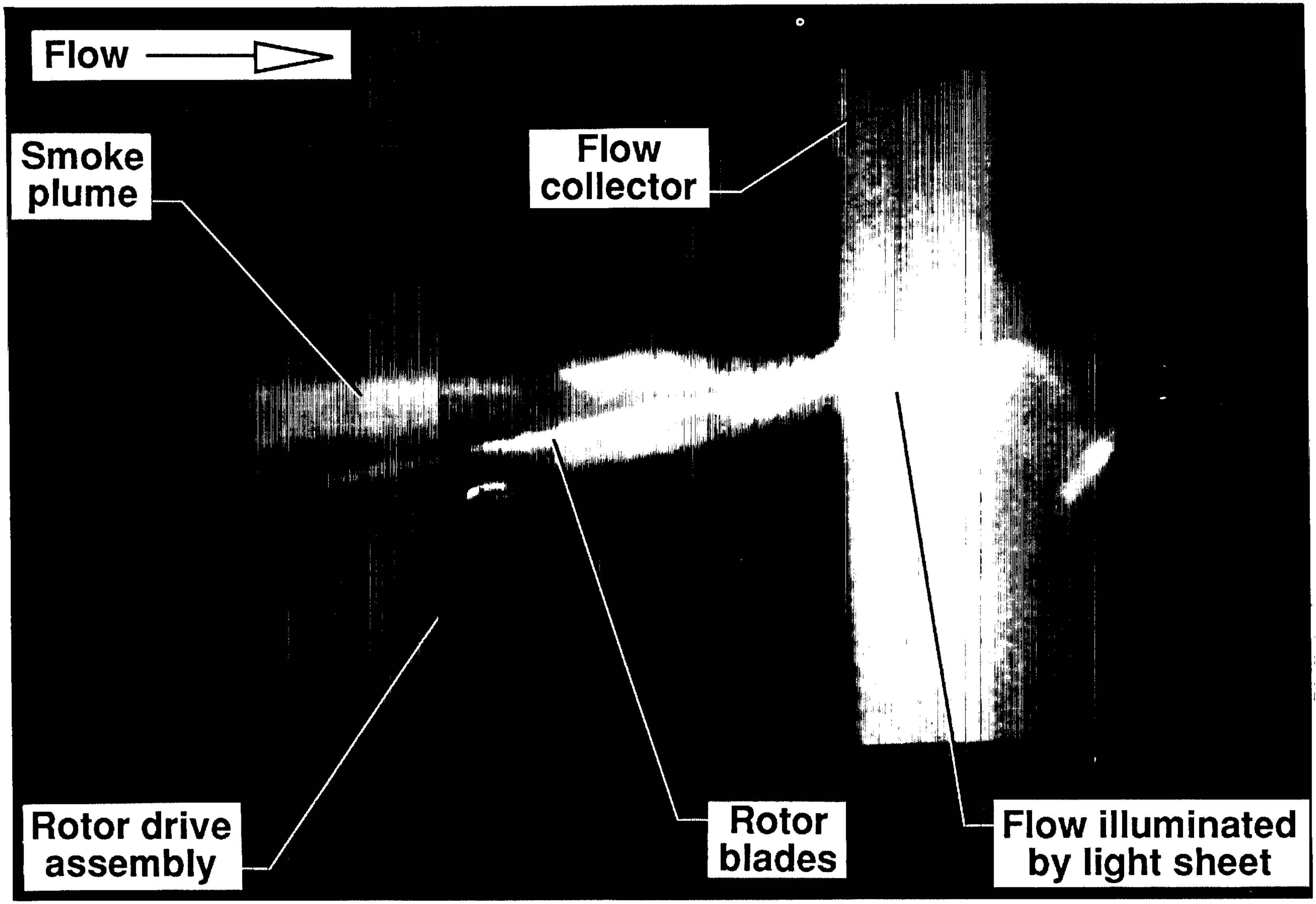

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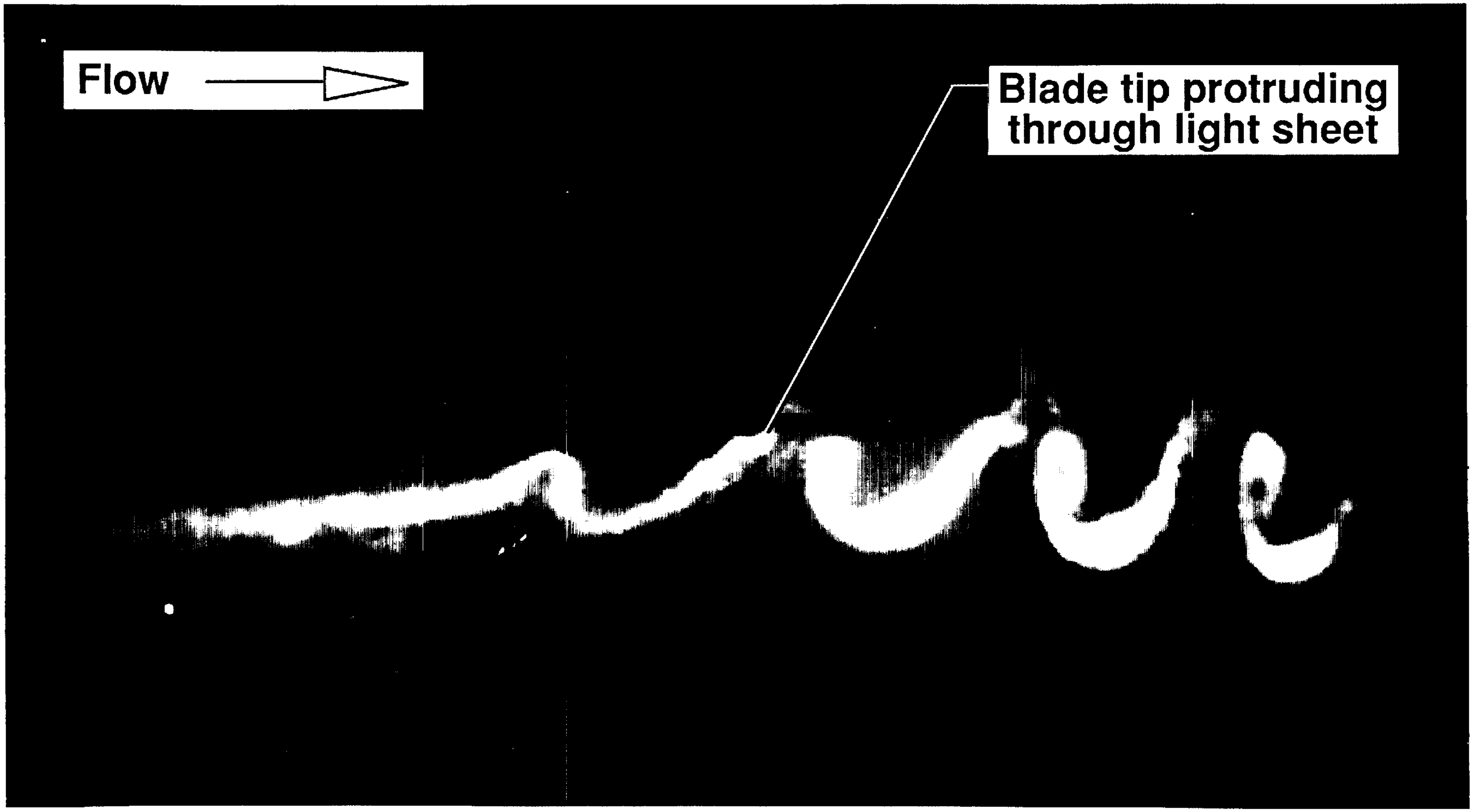
Figure 10. Experimental arrangement during tunnel testing.



L-91-28

Figure 11. Example of how well the light sheet reveals consecutive rotor blade-tip vortices. Free-stream velocity, 263 ft/sec; tip velocity, 700 ft/sec; light sheet position, –60 percent; strobe angle, 0°.

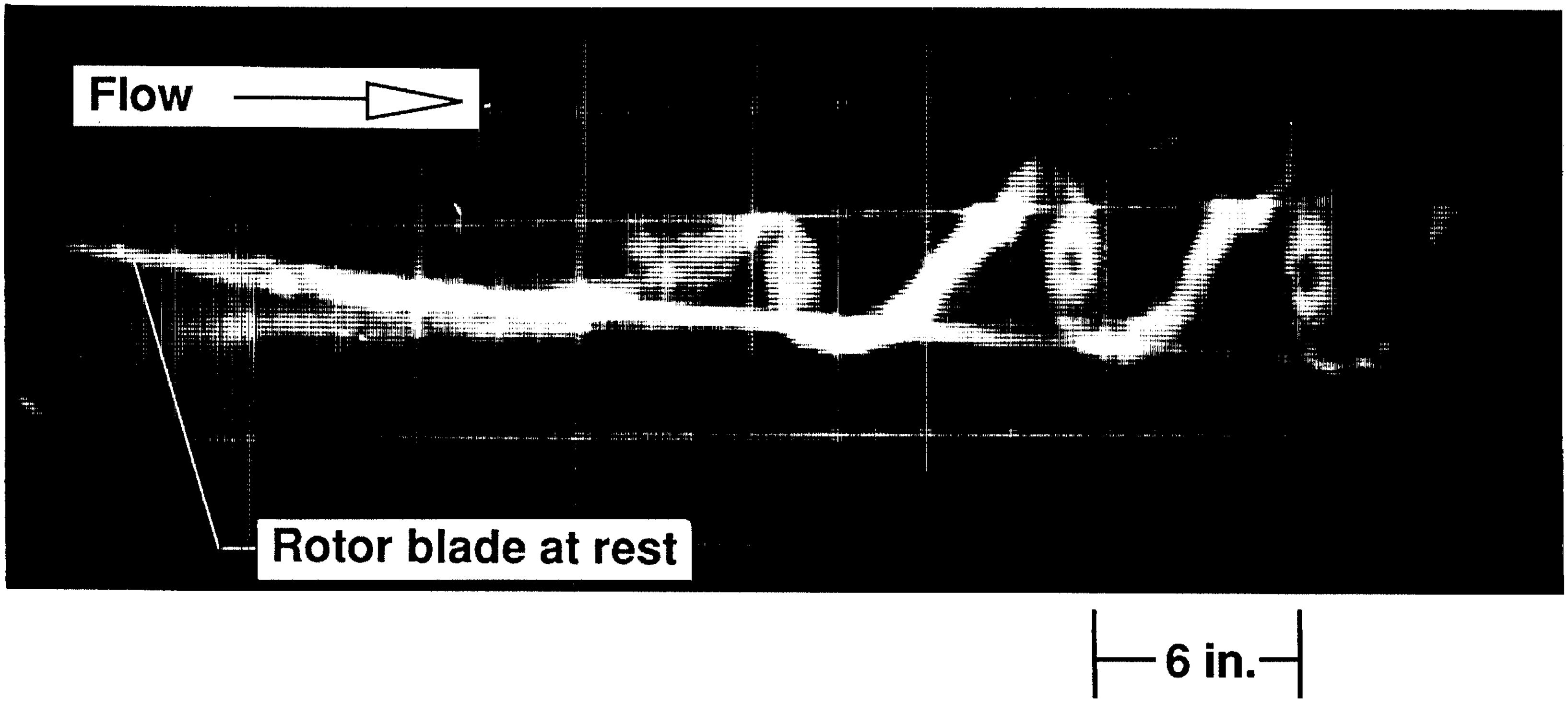


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Figure 12. Superimposed flow field and grid records. Free-stream velocity, 263 ft/sec; tip velocity, 700 ft/sec; light sheet position, –60 percent; strobe angle, 30°.

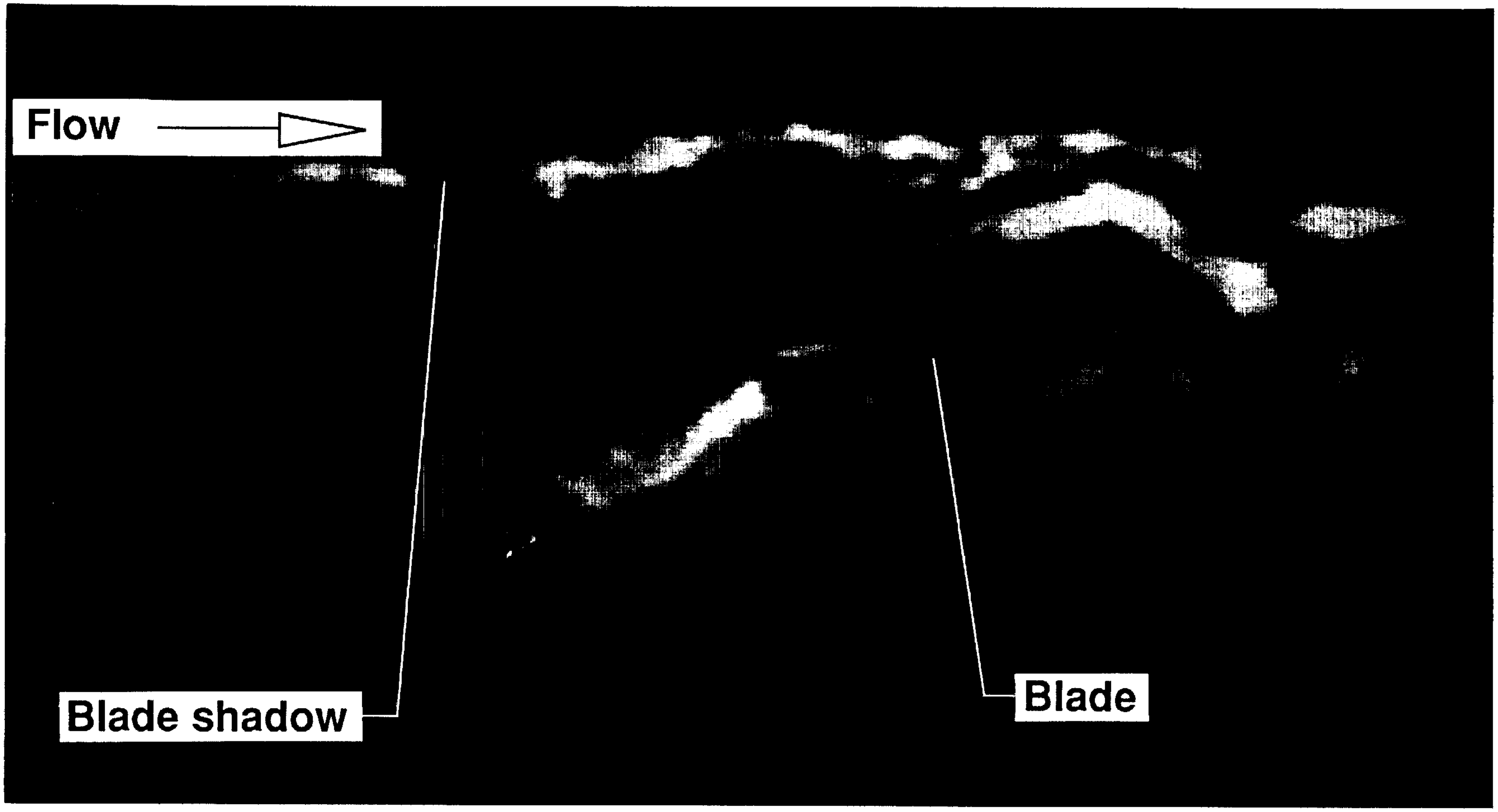

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Figure 13. Upper and lower rotor disk flow fields. Free-stream velocity, 263 ft/sec; tip velocity, 700 ft/sec; light sheet position, –60 percent; strobe angle, 0°.

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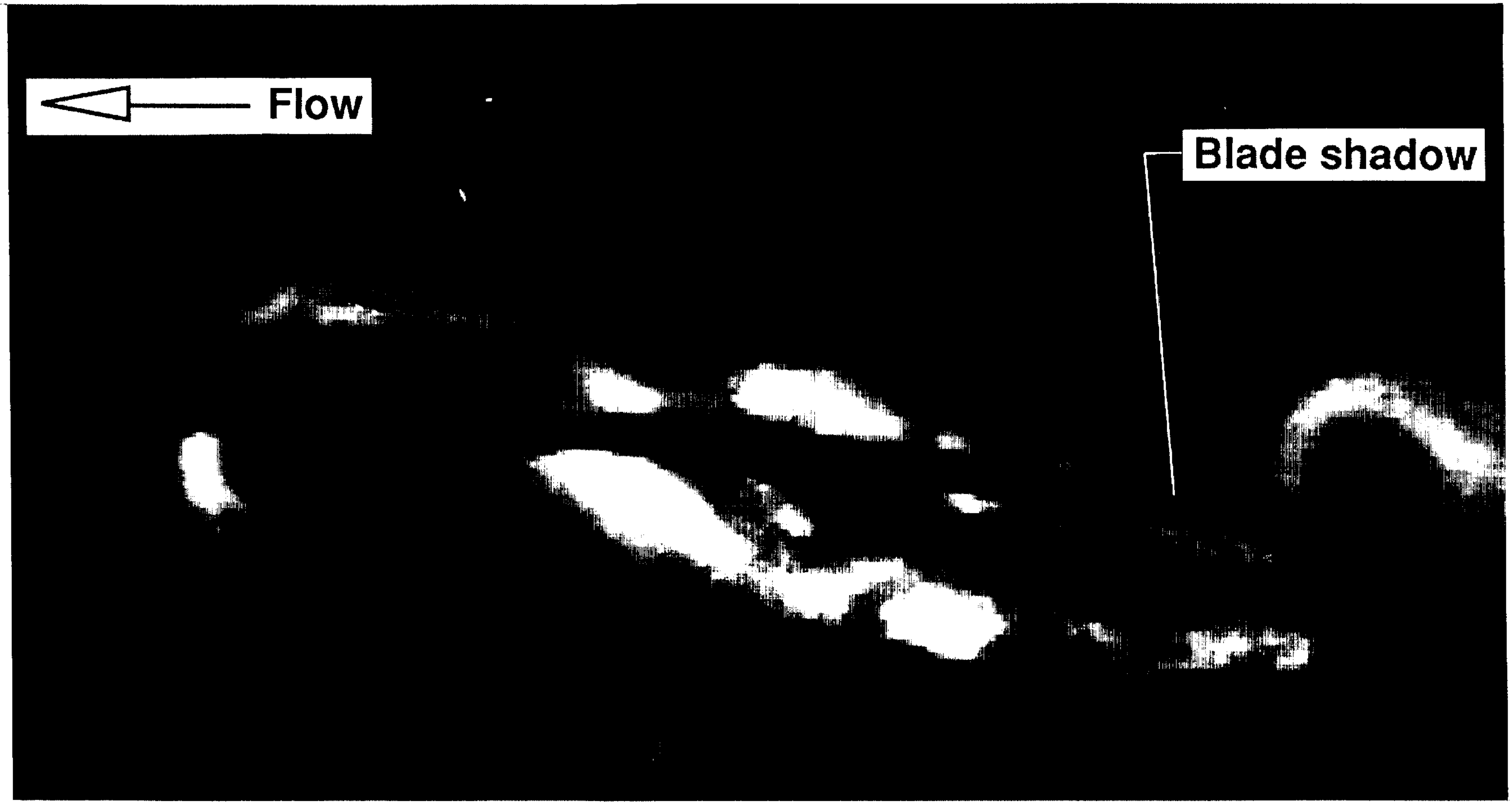

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Figure 14. Flow field pattern of 60-percent position as viewed from starboard side of test section. Free-stream velocity, 263 ft/sec; tip velocity, 700 ft/sec; light sheet position, 60 percent; strobe angle, 0°.

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15. Supplementary Notes

Much of the material contained in this report was presented on May 6, 1990, at the 36th International Instrumentation Symposium as a paper entitled "A Synchronous Strobed Laser Light Sheet for Helicopter Model Rotor Flow Visualization."

16. Abstract

A generating system of a synchronous strobed laser light sheet has been designed and used for flow visualization of a helicopter rotor model. The strobe circuit of the laser light sheet was designed to allow selectable blade-position viewing, strobe duration, and multiple pulses per revolution for rotors having two to nine blades. A slip-sync mode permits slow-motion visualization of the flow field over complete rotations of the rotor. The design has been tested in the NASA Langley 14- by 22-Foot Subsonic Tunnel where the flow was seeded with propylene glycol smoke. Between runs, a calibration grid board was placed in the plane of the laser sheet and recorded with the video camera at the position used to record the flow field. The system was used to make two-dimensional flow field cuts of a four-bladed rotor operating at wind-tunnel speeds up to 79.25 m/sec (260 ft/sec).

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